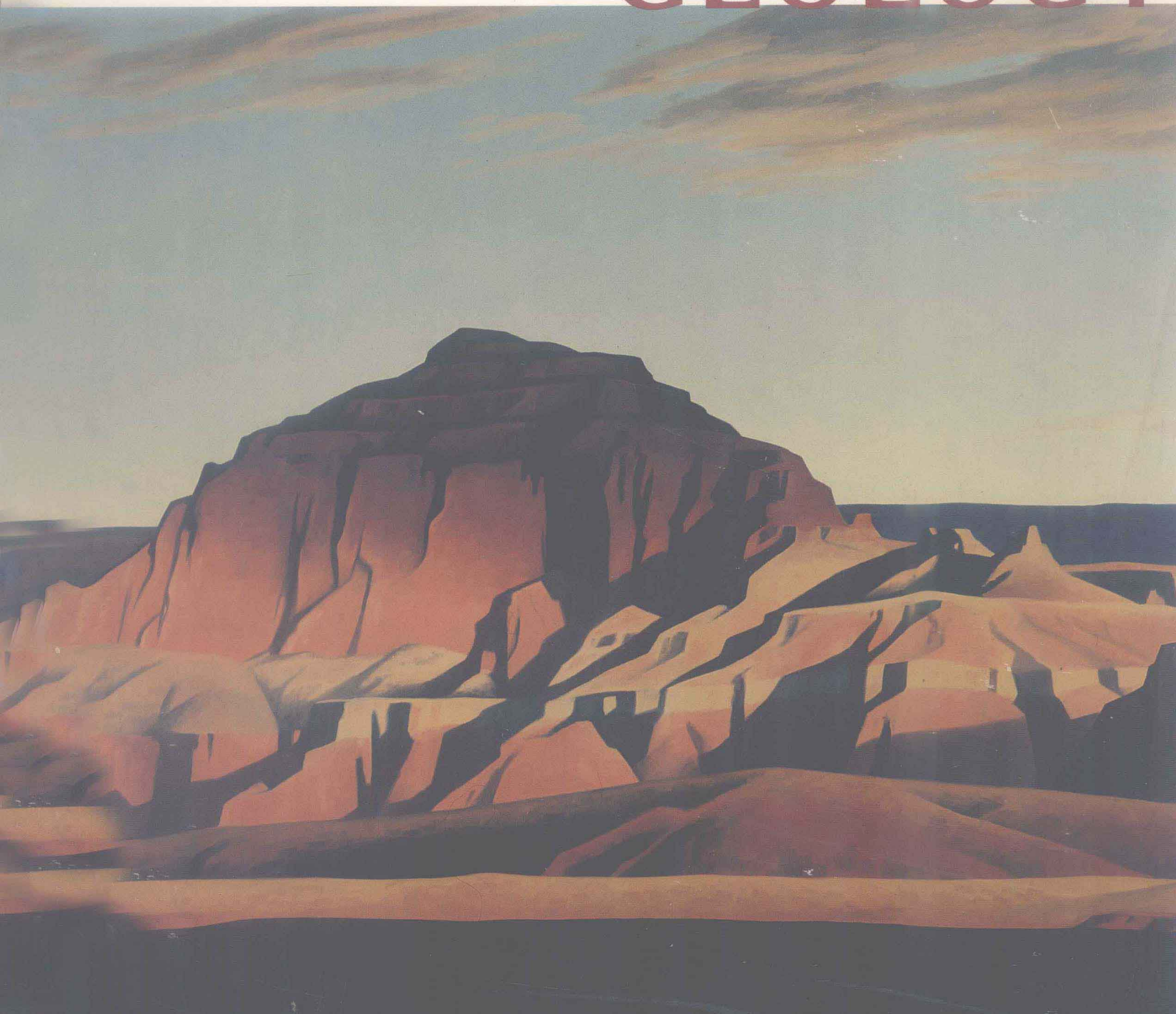
Chernicoff | Fox

SECOND EDITION

ESSENTIALS OF GEOLOGY



ESSENTIALS OF GEOLOGY

Second Edition

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Houghton Mifflin Company Boston New York

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Cover Painting: *Morning Light on Meeks Mesa* by Ed Mell, 1996, oil on canvas, 30″ x 96″.
Suzanne Brown Galleries, Scottsdale, Arizona.

Photo credits begin on page C-1.

Printed in the U.S.A.

Library of Congress Catalog Card Number: 99-71988

ISBN: 0-395-97055-5

2 3 4 5 6 7 8 9-VH-03 02 01 00 99

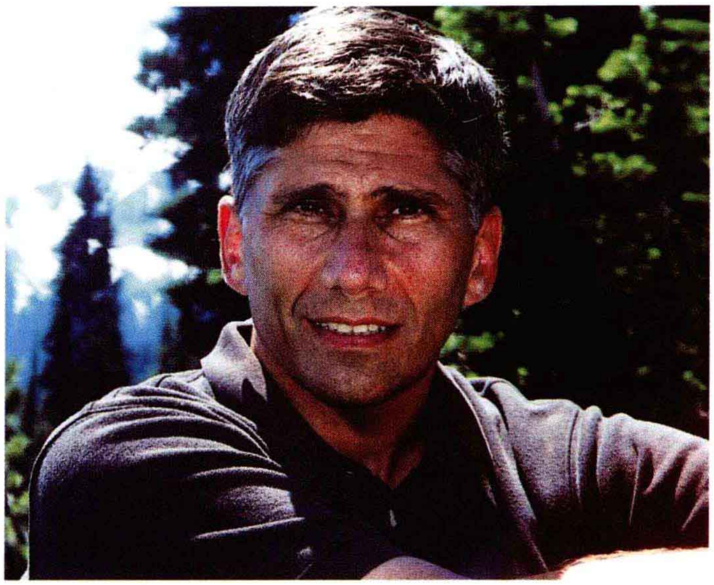
To my wife, Dr. Julie Stein, and my sons, Matthew and David, who have tolerated my obsession with text writing with extraordinary grace and humor (and endured an uncountable number of interrupted family dinners). Much thanks and appreciation for your remarkable support and encouragement.

Stan Chernicoff

To my wife, Jannie B. Fox, whose patience and encouragement were of limitless value in the writing of this book and in life in general.

Chip Fox

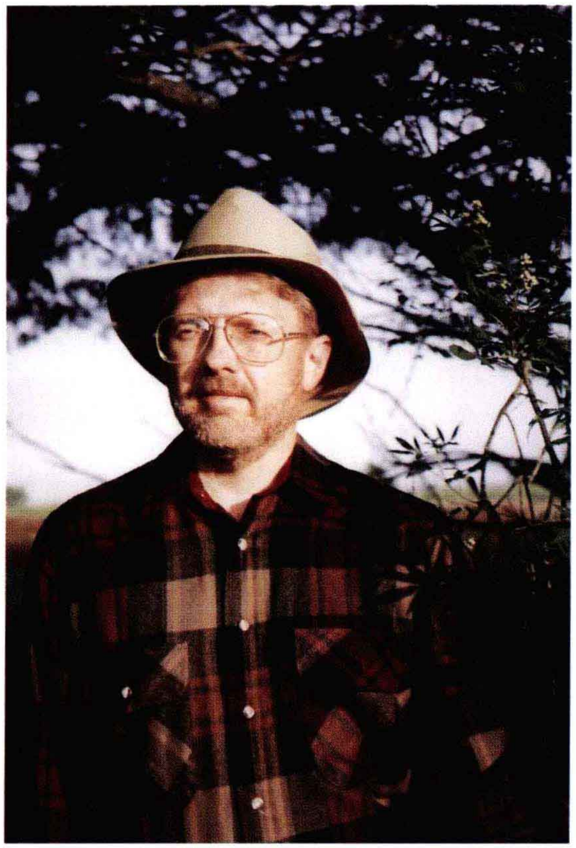
About the Authors



Born in Brooklyn, New York, Stan Chernicoff began his academic career as a political science major at Brooklyn College of the City University of New York. On graduation, he intended to enter law school and pursue a career in constitutional law. He had, however, the good fortune to take geology as his last requirement for graduation in the spring of his senior year, and he was so thoroughly captivated by it that his plans were forever changed.

After an intensive post-baccalaureate program of physics, calculus, chemistry, and geology, Stan entered the University of Minnesota–Twin Cities, where he received his doctorate in Glacial and Quaternary Geology under the guidance of one of North America's preeminent glacial geologists, Dr. H. E. Wright. Stan launched his career as a purveyor of geological knowledge as a senior graduate student teaching physical geology to hundreds of bright Minnesotans.

Stan has been a member of the faculty of the Department of Geological Sciences at the University of Washington in Seattle since 1981, where he has won several teaching awards. At Washington, he has taught Physical Geology, the Great Ice Ages, and the Geology of the Pacific Northwest to more than 20,000 students, and he has trained hundreds of graduate teaching assistants in the art of bringing geology alive for nonscience majors. Stan studies the glacial history of the Puget Sound region and pursues his true passion, coaching his sons and their buddies in soccer, baseball, and basketball. He lives in Seattle with his wife, Dr. Julie Stein, a professor of archaeology, and their two sons, Matthew (the midfielder, second baseman, two-guard) and David (the striker, second baseman, point guard).



Born in Grand Rapids, Michigan, Haydn A. "Chip" Fox received a bachelor's degree in theology and journalism from Ambassador College in Big Sandy, Texas, in 1971. He spent the next 15 years in several nonacademic pursuits, such as managing convenience stores, driving a truck, and working for a newspaper. In 1986, he returned to college with the intent of becoming an earth science teacher. His interests in geology, earth science, environmental science, and science education were immediately sparked, and in 1992 he received a Ph.D. in Geological Sciences from the University of South Carolina.

Chip has served on the faculty of departments of Earth Science at Southeast Missouri State University and Clemson University. He is currently a member of the faculty at Texas A & M University in Commerce, Texas, where he teaches numerous courses in earth science and the environmental sciences. Having spent several years in nonacademic careers, Chip understands the challenges his students will face when they graduate from college. He enjoys an excellent rapport with his students, a group that includes several future geologists, environmental professionals, and public school teachers.

Chip lives with his wife, Jannie, in an old farmhouse in Texas, where they are busy remodeling and trying to make a tenuous paradise of their 54 acres.

Preface

The introductory course in physical geology, taken predominantly by nonscience majors, may be the only science course some students will take during their college years. What a wonderful opportunity this provides us to introduce students to the field we love and show them how fascinating and useful it is. Indeed, much of what students will learn in their Physical Geology course will be recalled throughout their lives, as they travel across this and other continents, dig in backyards, walk along a beach, or sit by a mountain stream. For this reason, our book team—authors, illustrators, photo researchers, and editors—have expended the best of our abilities to craft an exciting, stimulating, and enduring introduction to the field.

The Book's Goal

The book's goal is basic—to teach what everyone should know about geology in a way that will engage and stimulate. The book embodies the view that this is perhaps the most useful college-level science class a nonscience major can take—one that we believe all students should take. Physical Geology can show students the essence of how science and scientists work, at the same time as it nurtures their interest in understanding, appreciating, and protecting their surroundings. In this course they can learn to prepare for any number of geologic and environmental threats, and see how our Earth can continue providing all of our needs for food, shelter, and material well-being as long as we don't squander these resources.

Content and Organization

Essentials of Geology extracts the most important concepts from Chernicoff's *Geology,* second edition, as they are typically taught in a nonmajors' geology course. All of the concepts are included to provide students with a general understanding of geology, but a more direct route is taken with each of the basics, rather than delving into the more detailed derivations of concepts, alternate theories, and additional details that encompass the vast body of knowledge related to every concept of geology.

The unifying themes of plate tectonics, environmental geology and natural resources, and planetary geology are introduced in Chapter 1 and discussed in their proper context within nearly every chapter. Chapter 1 also presents the three groups of rocks, the rock cycle, and geologic time—building a foundation for the succeeding chapters. Chapters 1 through 8 introduce the basics—minerals, rocks, and time. Part 2, Chapters 9 through 11, discuss structural geology, earthquakes, the Earth's interior, and the details of plate tectonics. Part 3, Chapters 12 through 19, presents the principal geomorphic processes of mass movement, streams, groundwater, and glaciers, as well as processes that occur in desert regions. The final two chapters, Chapters 18 and 19, tie together earlier discussions from throughout the book by discussing human use of Earth's resources and a brief history of Earth and its life forms.

New to the Second Edition of *Essentials of Geology*

A second edition is a wonderful opportunity to build on the first:

- To weave in the latest discoveries in the geosciences.
- To offer up-to-the-minute examples of exciting geological processes, such as the most recent volcanic eruptions and earthquakes.
- To rethink how concepts have been presented in the first edition—to clarify and illustrate them more effectively.

This—the second edition of *Essentials of Geology*—attempts to accomplish all of these goals, all to ensure that our students have the very best introductory experience with our science. Toward these ends, *Essentials* has included coverage of exciting areas like the following:

- An expanded discussion of the proposed origin of the Moon from a collision between the Earth and a Mars-sized impactor.
- Updates on recent and ongoing eruptions in the Caribbean (Montserrat), Mexico City, and New Zealand.
- The moment magnitude scale—an alternative to the Richter Scale.
- Using the global positioning system to track plate motion.
- Global warming, sea level, and coastal destruction.

These topics and many more constitute a substantial effort to ensure that a new edition of *Essentials of Geology* brings new ideas to its readers.

This edition of *Essentials of Geology* also benefits significantly from a change in text design. The new two-column format has enabled the book's designers to offer much-enlarged photos and illustrations—a concern from the first edition. Well over a hundred new photos have been selected (under the outstanding direction of Photo Researcher Townsend P. Dickinson) that illustrate most vividly the processes described in the text.

The Artwork

The drawings in this book are unique. Ramesh Venkatakrishnan is an experienced and respected geology professor and consultant. He is also a highly gifted artist. His drawings evolved along with the earliest drafts of the manuscript, sometimes leading the way for the text discussions.

As you will see when you leaf through this book, the art explains, describes, stimulates, and teaches. It is not schematic; it shows how the Earth and its geological features actually look. It is also not static; it shows geological processes in action, allowing students to see how geological features evolve through time. Every effort has been made to illustrate accurately a wide range of geological and geomorphic settings, including vegetation and wildlife, weathering patterns, even the shadows cast by the Sun at various latitudes. The artistic style is consistent throughout, so that students may become familiar with the appearance of some features even before reading about them in subsequent chapters. For example, the stream drainage patterns appearing on volcanoes in Chapter 4, Volcanoes and Volcanism, set the stage for the discussion of drainage patterns in Chapter 13, Streams and Floods. The colors used and the map symbols keyed to various rock types follow international conventions and are consistent throughout.

The second edition builds on the strengths of the art program of the first. The images in this edition have been enhanced digitally by renowned geology illustrators George Kelvin and John Woolsey to sharpen their focus, deepen their colors, and lend additional clarity and simplicity to their subjects. For this edition of *Essentials,* the maps have been rerendered by Patti Isaacs, Parrot Graphics, to add topographical relief where appropriate to give students a sense of context, and to make them brighter and cleaner and the labels easier to read.

Pedagogy

Nearly every chapter contains one or more Highlights—in-depth discussions of topics of popular interest that provide a broader view of the relevance of geology. In many cases, the Highlights comprise a late-breaking story that also shows the reader that the Earth's geology and its effects on us are changing daily.

To help readers learn and retain the important principles, every chapter ends with a Summary, a narrative discussion that recalls all of the important chapter concepts. Key terms, which are in boldface type in the chapter, are listed at the chapter's end and also appear in boldface in the Summary. Also at the end of every chapter are two question sets: *Questions for Review* helps students retain the facts presented, and *For Further Thought* challenges readers to think more deeply about the implications of the material studied.

The authors and illustrators have tried to introduce readers to world geology. This book emphasizes, however, the geology of North America (including the offshore state, Hawai'i), while acknowledging that geological processes do not stop at national boundaries or at the continent's coasts. Wherever data are available—from the distribution of coal to the survey of seismic hazards—we have tried to show our readers as much of this continent, and beyond, as feasible. Photos and examples have been selected from throughout the United States and Canada and from many other regions of the world.

The metric system is used for all numerical units, with their English equivalents in parentheses, so that U.S. students can become more familiar with the units of measurement used by virtually every other country in the world.

The Supplements Package

Essentials of Geology is accompanied by an array of materials to enhance teaching and learning.

Students who wish additional help mastering the text can use the Study Guide by W. Carl Shellenberger (Montana State University—Northern). For each chapter, the Guided Study section helps students focus on and review in writing the key ideas of each section of the chapter as they read. The Chapter Review, arranged by section and composed of fill-in statements, enables them to see if they have retained the ideas and terminology introduced in the chapter. The Practice Tests and the Challenge Test, which consist of multiple-choice, true/false, and brief essay questions, test their mastery of the material. All answers are accompanied by page references for easy review.

The Instructor's Resource Manual by Chip Fox features an outline lecture guide with teaching suggestions embedded in it and student activities and classroom demonstrations. Answers to the end-of-chapter questions in the textbook are also provided. Also included is a comprehensive Test Bank, compiled by Chip Fox, that contains more than one thousand questions. There are at least 40 multiple-choice questions per chapter, classified as either factual or conceptual/analytical. There are also ten short essay questions, complete with answers, for each chapter. A computerized version of the Test Bank is available in both IBM and Macintosh formats.

Also available with this edition is the *Geology Laboratory Manual* by James D. Myers, James E. McClurg, and Charles L. Angevine of the University of Wyoming. This inexpensive manual is closely tied to the text and offers twenty physical geology labs on topics such as maps, plate tectonics, sedimentary and metamorphic rocks, streams, and groundwater. Each lab contains multiple activities to develop and hone students' geological skills. Worksheets are designed to be torn from the manual and submitted for grading.

More than 130 of the text's diagrams and photographs are available for classroom use as full-color slides or transparencies.

The book is supported further by its award-winning web site, GEOLOGYLINK (found at www.geologylink.com), maintained and updated regularly by its web master, Rob Viens of the University of Washington. This site will tell you what of geological import has happened overnight while you slept. It also contains expanded discussions of "hot topics" in the field of geology and an exhaustive encyclopedia of links to all things geological. For the second edition of *Essentials of Geology,* GEOLOGYLINK contains chapter quizzes and tutorials as well as an on-line version of the Peterson's *Field Guide to Rocks and Minerals* by Frederick Pough. These outstanding teaching and learning aids help the student learn physical geology through multimedia technology, study physical geology in a stimulating, yet thoughtful way, and master the principles of physical geology.

Acknowledgments

Some remarkably talented, dedicated people have helped us accomplish far more than we could have done alone. A "committee" of top-flight geologists has been assembled who have dramatically clarified definitions and explanations, eliminated ambiguities, corrected factual errors and fuzzy logic, and, in general, helped the authors hone the manuscript in countless ways and helped the illustrator select what to show and how best to do it. Special thanks must go to Kurt Hollocher of Union College and L. B. Gillett of SUNY-Plattsburgh for their extremely insightful critiques of the first edition. In addition, for their constructive criticism at various stages along the way, we wish to thank these excellent reviewers:

From the first edition of *Geology:*

Gail M. Ashley, *Rutgers University, Piscataway*

David M. Best, *Northern Arizona University*

David P. Bucke, Jr., *University of Vermont*

Michael E. Campana, *University of New Mexico*

Joseph V. Chernosky, Jr., *University of Maine, Orono*

G. Michael Clark, *University of Tennessee, Knoxville*

W. R. Danner, *University of British Columbia*

Paul Frederick Edinger, *Coker College (South Carolina)*

Robert L. Eves, *Southern Utah University*

Stanley C. Finney, *California State University, Long Beach*

Roberto Garza, *San Antonio College*

Charles W. Hickox, *Emory University*

Kenneth M. Hinkel, *University of Cincinnati*

Darrel Hoff, *Luther College (Iowa)*

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Allan M. Thompson, *University of Delaware*

Charles P. Thornton, *Pennsylvania State University*

From the second edition of *Geology:*

William W. Atkinson, *University of Colorado, Boulder*

Joseph Chernosky, *University of Maine, Orono*

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Katherine Giles, *New Mexico State University*
L. B. Gillett, *SUNY-Plattsburgh*
Kurt Hollocher, *Union College*
Kathleen Johnson, *University of New Orleans*
Judith Kusnick, *Cal-State Sacramento*
Bart Martin, *Ohio Wesleyan University*
Ronald Nusbaum, *College of Charleston*
Meg Riesenberg
Roger Stewart, *University of Idaho*
Donna L. Whitney, *University of Minnesota*

From the second edition of *Essentials of Geology:*

Andrew Buddington, *Spokane Community College*
Timothy L. Clarey, *Delta College*
Dale H. Easley, *University of New Orleans*
Terry Engelder, *Pennsylvania State University*
Brice M. Hand, *Syracuse University*
Lindley S. Hanson, *Salem State College*
Richard Robinson, *Santa Monica College*
Robert D. Shuster, *University of Nebraska at Omaha*
David W. Valentino, *State University of New York at Oswego*

We would also like to thank William A. Smith (Charleston Southern State University) for his sharp eye in reviewing the art for accuracy.

At Houghton Mifflin, developmental editors Virginia Joyner and Marjorie Anderson, working under oppressive time constraints, performed the arduous task of reining in the authors' long-windedness with extraordinary grace and intelligence and brought organization wherever they found disorder. Senior Associate Sponsor Sue Warne, Senior Project Editor Chere Bemelmans, Art Editor Charlotte Miller, Copyeditor Jill Hobbs, and Editorial Assistant Joy Park polished each chapter of prose and every rough sketch, working with all the elements of the book until they formed a coherent whole. Photo research was handled masterfully by Photo Researchers Townsend P. Dickinson and Mardi Welch Dickinson. The book's pleasing appearance was created under the supervision of Senior Production/Design Coordinator Jill Haber, Associate Production/Design Coordinator Jodi O'Rourke, and Layout Designer Penny Peters. We very much appreciate Editor-in-Chief Kathi Prancan's support and behind-the-scenes hard work and Executive Marketing Manager Andy Fisher's energetic marketing support. Thanks are due also to Associate Editor Marianne Stepanian, who coordinated and edited the supplements.

Finally, we also wish to acknowledge with deep appreciation the role of Ron Pullins (formerly of Little, Brown and now of Focus Publishing) and Kerry Baruth (formerly of Worth Publishers and now of Houghton Mifflin), who championed the cause of *Essentials of Geology* with their respective companies during its early gestation.

After they leave our classrooms, students may well forget some specific facts and terminology of geology, but they will still retain the general impressions and attitudes they formed during our course. We hope that our words and illustrations will help advance the goals of those teaching this course and contribute to their classes. We have used our teaching experiences to craft a textbook that we think our own students will learn from and enjoy. We hope your students will, too. We invite your comments: please send them to the authors, whose e-mail addresses are sechern@u.washington.edu and haydn_fox@tamu-commerce.edu.

Stan Chernicoff
Haydn A. "Chip" Fox

To the Student

Only a very few years ago, I was an undergraduate "nontraditional" student in college being exposed to geology for the first time. As occurs with a surprisingly large number of students, the spark for geology and the other earth sciences was kindled almost immediately. I have little doubt that you, too, will find your study of geology to be most interesting.

One of the appeals of geology is its application to everyday life. All around you are hills or mountains, valleys, coastlines, and soils; it is geology that tells you why these things are there and how they formed. Every local area has it own geology, which is part of a much larger picture of regional and even world geology.

On my van is a bumper sticker that reads, "If it can't be grown, it has to be mined." Everything we have comes either from growing things or from finding them somewhere within the ground. It is in the realm of geology to determine where the products we mine are located, and to understand how and under what situations they form. As if this weren't a large enough body of knowledge to encompass, it is also in the realm of geology to explore the inner workings of volcanoes and earthquakes, the interior structure of the Earth, and the functions of rivers, glaciers, and a host of other natural phenomena.

Geology is the basis for much of our understanding of the environment. If you become interested in pursuing a career in environmental sciences, you will find geology at the cornerstone. Most environmental consultants, and many people involved in environmental compliance (working for governments, large corporations, or industry) have come from the field of geology.

This book presents a brief survey of the whole field of geology, from rocks and minerals to the formation of entire continents and the processes that act upon and under them. This overview will provide you with a basis for understanding many different aspects of our planet, and it may even entice you to explore them further. If so, you will discover that there is a world of knowledge behind every topic mentioned in this book, each of which could lead to an exciting and challenging career.

Haydn A. "Chip" Fox

Features of

Essentials of GEOLOGY,

Second Edition

The rich detail and technical accuracy of the illustrations help convey complex concepts to introductory students.

Photos are often paired with art to emphasize a point.

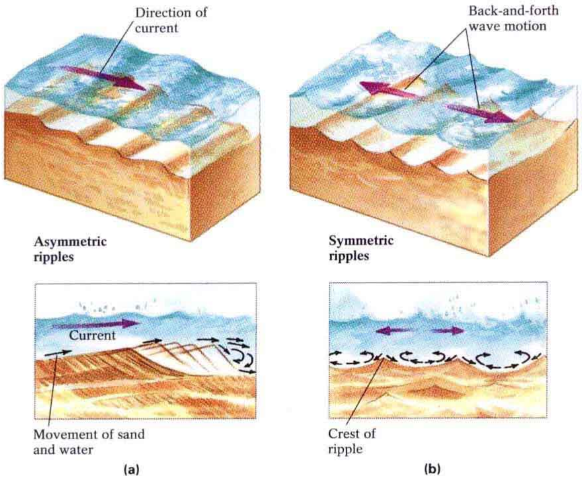


Figure 6-7 Different types of currents produce different ripple patterns. (a) A current that generally flows in one direction, such as a stream, produces asymmetric ripples. Sand grains roll up the gently sloping upstream side of each ridge and then cascade down the steeper downstream side. **(b)** Symmetric ripples form from the back-and-forth motion of waves in shallow surf zones at the coast or at the water's edge in a lake. Photo: Exposed rocks show ripple marks, evidence of past current flow, either water or wind.

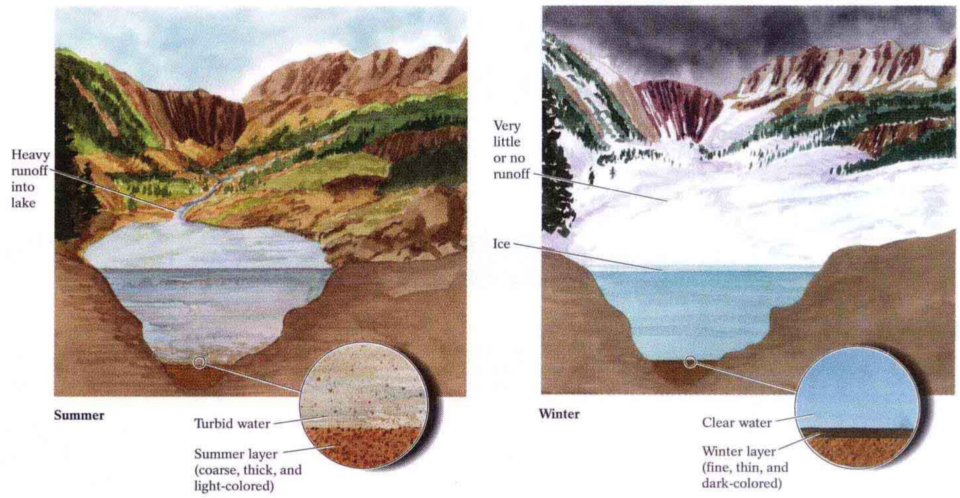
series of shallow curving ridges. The configuration of these ridges, which are often visible on sandy surfaces, reflects the nature of the current that produced them (Fig. 6-7).

Mudcracks are fractures that develop when the surface of wet fine-grained sediment (mud) dries and contracts (Fig. 6-8). Because these structures form only at the top of a layer of muddy sediment and narrow progressively downward, geologists can study mudcracks to determine whether a layer of sedimentary rock has been overturned.

Lithification: Turning Sediment into Sedimentary Rock

When a sediment layer is deposited, it buries all previous layers deposited at that location. Eventually, the continuing deposition may enable a sedimentary pile to become several kilometers deep. Such deep burial may convert sediments into solid sedimentary rock by the process of **lithification** (from the Greek *lithos,* meaning "rock," and Latin *facere,* meaning "to make"). During lithification, sediment grains become compacted, often cemented, and sometimes recrystallized.

Compaction is the process by which the volume of buried sediment, either detrital or chemical, becomes diminished by pressure exerted by the weight of overlying sediments. Expulsion of air and water from the sediment and the reduction of the spaces between grains combine to



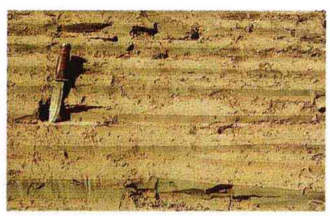


Figure 8-13 The origin of lake varves. A typical varve includes a thick, coarse, light-colored summertime layer produced during high runoff (from snowmelt and spring storms) and high sediment influx, plus a thin, fine dark-colored wintertime layer produced during low runoff and low sediment influx (or no influx, if the lake is frozen). Note the varves in the photo. Why do you think the varves vary so noticeably in thickness?

Artwork shows geologic features in a naturalistic context, to give students a sense of how these features actually look.

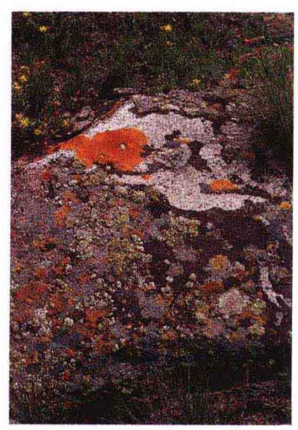


Figure 8-14 Lichen colonies on a granite boulder. The light-colored areas of rock have been bleached by chemicals in the lichen. The sizes of such colonies can provide clues as to how long the rock surface has been exposed.

deposited in summer and a thin, fine, dark-colored layer deposited in winter. By applying *varve chronology,* in which they study the number and nature of the varves underlying a lake, geologists can determine how long ago the lake formed and identify events, such as landslides, that affected sedimentation in the area (Fig. 8-13).

Lichen (pronounced "LIE-ken"), colonies of simple, plant-like organisms that grow on exposed rock surfaces, are the basis of a dating method known as *lichenometry*. Lichen grow extremely slowly; given similar rocks and climatic conditions, the larger the lichen colony, the longer the period of time since the growth surface was exposed. Study of these organisms can yield accurate dates for young glacial deposits, rockfalls, and mudflows—all events that expose new rock surfaces on which lichen can grow (Fig. 8-14).

Highlight 12-2 How to Choose a Stable Home Site

If you have not already done so, you may eventually wish to purchase your own home. Having studied physical geology, you will want to ensure that your dream house doesn't fall victim to a geological nightmare.

Suppose you're exploring southern California's scenic beachfront locales. You happen upon the mosaic sign for the town of Portuguese Bend and notice that the beautiful ceramic signpost is cracked into two pieces. You check the local real estate listings and find a house priced at $50,000 that should be worth $500,000. Your knowledge of geology, along with your common sense, immediately warns you that something may be wrong here. What else should you look for? How can you tell—in southern California or anywhere else in the world—if you're in mass-movement country?

Examine both the property itself and the entire neighborhood. Do you see any signs of an old mud or debris flow? Is there evidence of a slump scar upslope where a block may have broken away? As you drive through the community and its environs, look for fences that are out of alignment, and for power and telephone lines that seem too slack in some places and too taut in others (Fig. 1).

Next, look carefully at the house itself and, if possible, at neighboring ones. Search for large cracks in the foundation (small cracks may be due to initial drying and settling of the concrete). Doors and windows that stick may indicate that once-linear structural features are now out of line, although poor craftsmanship or high moisture content may also be responsible. A cracked pool lining might explain why a swimming pool doesn't retain water. Finding only one such problem may not indicate danger, but the presence of several problems should send a strong warning signal. If the geology, topography, and hydrology of a home site all raise questions about slope stability, the site may well be prone to progressive slope failure. To confirm your suspicions, try checking newspaper accounts and the records of the local housing authority, contacting the state geological survey, and interviewing the property's neighbors.

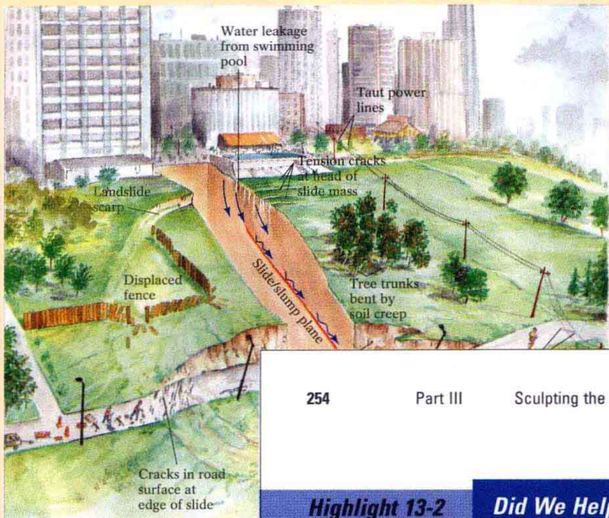


Figure 1 Various signs of past, current, and potential future mass movement in an urban area. If the power lines in a neighborhood are very loose, it suggests that the poles that hold them have moved closer together, as one might expect at the toe of a slide where the slope is bunching up like a rumpled carpet. At the head of the slide, taut lines may indicate that the poles on the slide mass are moving away from those upslope. The poles in the middle of a slide mass may keep their original spacing, because the mass may not be deforming much internally.

Highlight boxes introduce high-interest topics, making geology relevant to students' lives.

Highlight 13-2 Did We Help Cause the Midwestern Flood of 1993?

In the beginning of this chapter, we discussed one of North America's worst floods, which took place along the upper portions of the Mississippi River in the summer of 1993 (Fig. 1). Did human activity—65 years of "managing" the Mississippi River to prevent floods—actually contribute to the magnitude and tragedy of the flood?

Before the last 100 years or so, the Mississippi and its tributaries determined their own boundaries. During periods of high water, the rivers broke through or overflowed natural levees, flooding tens of thousands of square kilometers of the surrounding, largely uninhabited, lands. In the twentieth century, however, millions of people migrated to the region, building cities, towns, and large farms along the rivers' banks. When a flood in 1927 took 214 lives, Congress enacted the first Mississippi River Flood Control Act, assigning the U.S. Army Corps of Engineers the daunting task of confining the river to its channel.

The Corps of Engineers' efforts consist of about 300 dams and reservoirs and thousands of kilometers of artificial levees and concrete flood walls, all designed to prevent the river from spilling onto its natural floodplain. The system also contains numerous pumping stations, spillways, and diversion channels designed to divert water for storage in temporary holding basins. But the events of 1993 showed that such structures simply cannot contain an extraordinary flood. By confining such great discharges to a channel, the artificial retention structures actually caused the swollen rivers to flow more rapidly and violently, thus damaging the very structures designed to restrain them. By denying the river access to its natural floodplains, the structures caused the streams to rise higher than they would have otherwise, ensuring that once they did breach the levees, the floods would cause greater damage. Furthermore, the existence of artificial levees and flood walls had encouraged the growth of cities, towns, and farms closer to the riverbanks than was really safe.

What does the future hold for the residents of the upper Mississippi valley? Certainly more flooding, but perhaps less human interference with the river's natural behavior. Some communities have proposed that all flood-retention systems be eliminated and that zoning limit future development within the river's floodplain. Others look longingly at St. Louis's 16-meter (52-foot)-high concrete flood wall, which saved that city's downtown business district when the Mississippi reached its record crest at 14.2 meters (47 feet). The debate continues between those who believe we can tame the mighty Mississippi and those who believe we cannot.

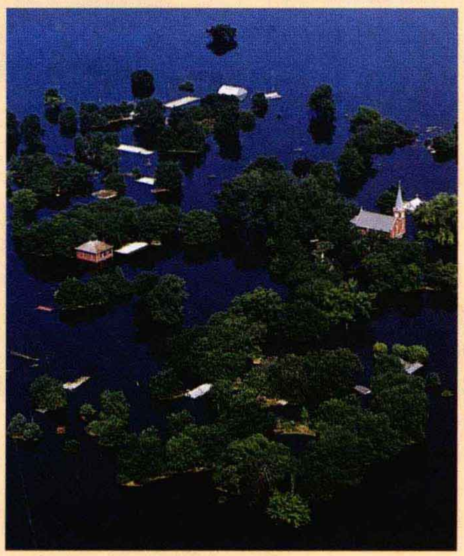


Figure 1 Flooding at Kaskaskia, Illinois.

Chapter Summary

Volcanism, the set of processes that results in extrusion of molten rock, begins with the creation of magma by the melting of preexisting rock and culminates with the ascent of this magma to the Earth's surface through fractures, faults, and other cracks in the lithosphere. **Volcanoes** are the landforms created when molten rock escapes from vents in the Earth's surface and then solidifies around these vents. Volcanoes may be active, dormant, or extinct.

Because of its high temperature and relatively low silica content, mafic magma has low viscosity (is highly fluid). It generally erupts (as basaltic lava) relatively quietly, or effusively, because its gases can readily escape and do not build up high pressure. Felsic magma, with its high silica content and relatively low temperature, is highly viscous and generally erupts (as rhyolitic lava) explosively.

The nonexplosive volcanic eruptions characteristic of basaltic lava produce lava flows that, when they solidify, are associated with distinctive features such as pahoehoe- and 'a'a-type surface textures, basaltic columns, lava tubes, and pillow structures. The explosive volcanic eruptions characteristic of rhyolitic lavas typically eject **pyroclastic** material—fragments of solidified lava and shattered preexi… rock ejected forcefully into the atmosphere. The variou… ticles produced when lava cools and solidifies as it falls… to the surface are collectively called **tephra.** Explosive… tion of pyroclastic material is usually accompanied by a… ber of life-threatening effects, such as **pyroclastic flow**… **nuée ardentes** (high-speed, ground-hugging avalanches… pyroclastic material), and **lahars** (volcanic mudflows).

Nearly all volcanoes have the same two major co… nents: (1) a mountain, or **volcanic cone,** built up of the… ucts of successive eruptions; and (2) a bowl-shaped de… sion, or **volcanic crater,** surrounding the volcano's ve… enough lava erupts to empty a volcano's subterranean… voir of magma, the cone's summit may collapse, form… much larger depression, or **caldera.**

Effusive eruptions, which usually involve basaltic… form gently sloping, broad-based cones called **shield v… noes.** Basaltic magma reaching the surface through lon… ear cracks, or fissures, in the Earth's crust spreads to pr… nearly horizontal lava plateaus.

Explosive **pyroclastic eruptions** involve viscous, us… gas-rich magmas and so tend to produce great amour… solid volcanic fragments rather than fluid lavas. Felsic… olitic) lavas are often so viscous that they cannot flow… a volcano's crater; they therefore cool and harden within… craters to form **volcanic domes.** Ash-flow eruptions occ… the absence of a volcanic cone; they are produced whe… tremely viscous, gas-rich magma rises to just below th… face bedrock, stretching and collapsing it.

The characteristic landform of pyroclastic eruptic… the **composite cone,** or **stratovolcano,** which is compos… alternating layers of pyroclastic deposits and solidified lava. Pyroclastic eruptions may also produce **pyroclastic cones** or **cinder cones,** created almost entirely from the accumulation of loose pyroclastic material around a vent. All pyroclastic-type volcanoes produce steep-sided cones, because the materials they eject—solid fragments and highly viscous lavas—do not flow far from the vent.

Various types of volcanic eruptions are associated with different plate tectonic settings. Explosive pyroclastic eruptions of felsic (rhyolitic) lava generally occur within continental areas characterized by plate rifting or atop intracontinental hot spots. Most intermediate (andesitic) eruptions take place near subducting oceanic plates. Effusive eruptions of (mafic) basalt generally occur at divergent plate margins and above oceanic intraplate hot spots.

Humans can minimize damage from volcanoes by zoning against development in the most hazardous areas, building lava dams, diverting the path of a flowing lava, and learning to predict eruptions accurately. Techniques used to predict eruptions include measuring changes in a volcano's slopes, recording related earthquake activity, and tracking changes in the volcano's external heat flow.

Volcanism is not restricted to the Earth. It has occurred in the past on the Moon, and relatively recent volcanic ac-…

End-of-chapter summaries present an overview of the content in narrative form to help students review.

granites are formed within continents by partial melting of the lower portions of the continental crust; these types of igneous rocks are often associated with subduction-produced mountains.

Igneous rocks are also found on the Moon. Lunar igneous rocks differ fundamentally from those on Earth, in that they contain no water and their formation involved neither plate tectonics nor subsurface heat. The Moon's surface consists of highlands composed largely of anorthosite, a coarse-grained plutonic igneous rock, and vast areas of basalt known as maria.

Igneous rocks are valued for the gemstones and precious metals they contain. They are also used for a variety of practical purposes, such as road construction, architectural design, and household abrasives.

Key Terms

igneous rocks (p. 41)
magma (p. 42)
lava (p. 42)
intrusive rocks (p. 43)
plutonic rocks (p. 43)
extrusive rocks (p. 43)
volcanic rocks (p. 43)
peridotite (p. 45)
basalt (p. 45)
gabbro (p. 46)
andesite (p. 46)
diorite (p. 46)
granite (p. 46)
rhyolite (p. 46)
partial melting (p. 46)
Bowen's reaction series (p. 48)
fractional crystallization (p. 49)
plutons (p. 50)
dike (p. 51)
sill (p. 53)
laccolith (p. 53)
lopoliths (p. 53)
batholiths (p. 53)
andesite line (p. 55)

Questions for Review

1. Briefly describe the textural difference between phaneritic and aphanitic rocks. Why do these rocks have different textures?

2. Some igneous rocks contain large visible crystals surrounded by microscopically small crystals. What are these rocks called? How does such a texture form?

3. What elements would you expect to predominate in a mafic igneous rock? In a felsic igneous rock?

4. Name the common *extrusive* igneous rocks in which you would expect to find each of the following mineral types: calcium feldspar; potassium feldspar; muscovite mica; olivine; amphiboles; sodium feldspars. Which *plutonic* igneous rock contains abundant quartz and muscovite mica, but virtually no olivine or pyroxene?

5. What factors, in addition to heat, control the melting of rocks to generate magma?

6. What is the basic difference between the continuous and discontinuous series of Bowen's reaction series?

7. Briefly describe three things that might happen to an early-crystallized mineral surrounded by liquid magma.

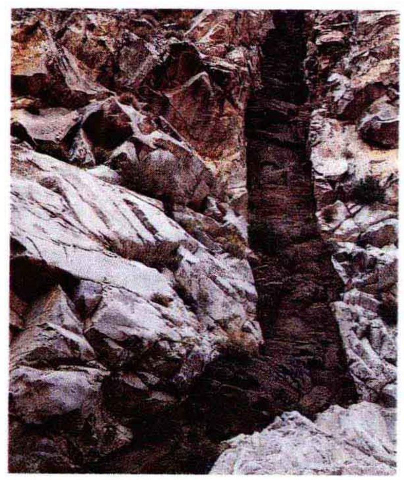
8. How do a sill and a dike differ? A laccolith and a lopolith? A lopolith and a batholith?

9. Briefly discuss two specific types of plate tectonic boundaries and the igneous rocks that are associated with them.

10. What is the basic difference between a mid-ocean ridge basalt and an oceanic island basalt?

For Further Thought

1. What type of igneous feature is shown in the photo below?



2. Felsic rocks such as rhyolite often occur together with basaltic rocks near rifting continents. Give one possible explanation for this pairing.

3. Why do we rarely find batholiths made of gabbro?

4. How might the distribution of the Earth's igneous rocks change when the Earth's internal heat is exhausted and plate tectonic movement stops?

5. Why are there virtually no granites or diorites on the Moon? How might small volumes of such felsic rock form under the geological conditions believed to be responsible for the Moon's igneous rocks?

The Key Term list is a tool for quick review and gives the page number for the full discussion, for students who need to reread the material. (The terms also appear in the glossary.)

Questions for Review help students review the factual content of the chapter, and For Further Thought questions encourage them to think critically about the implications of the information they have learned.

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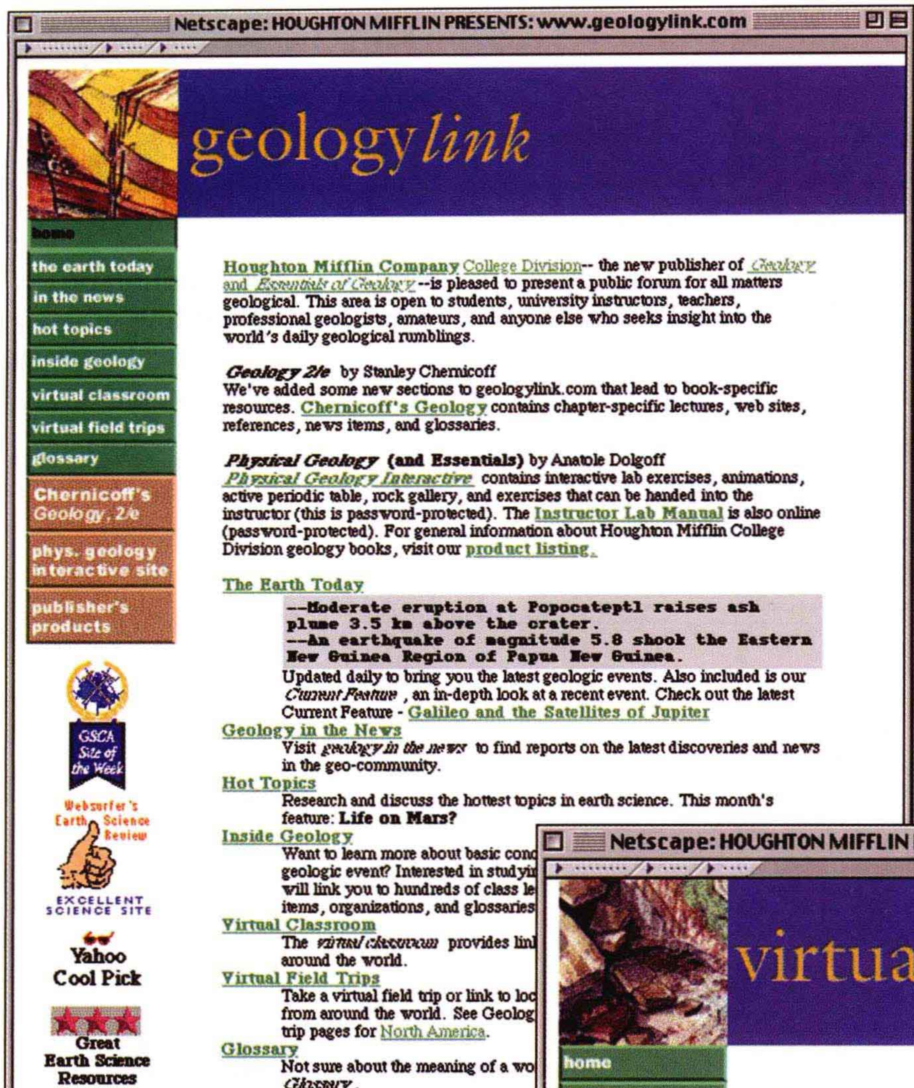
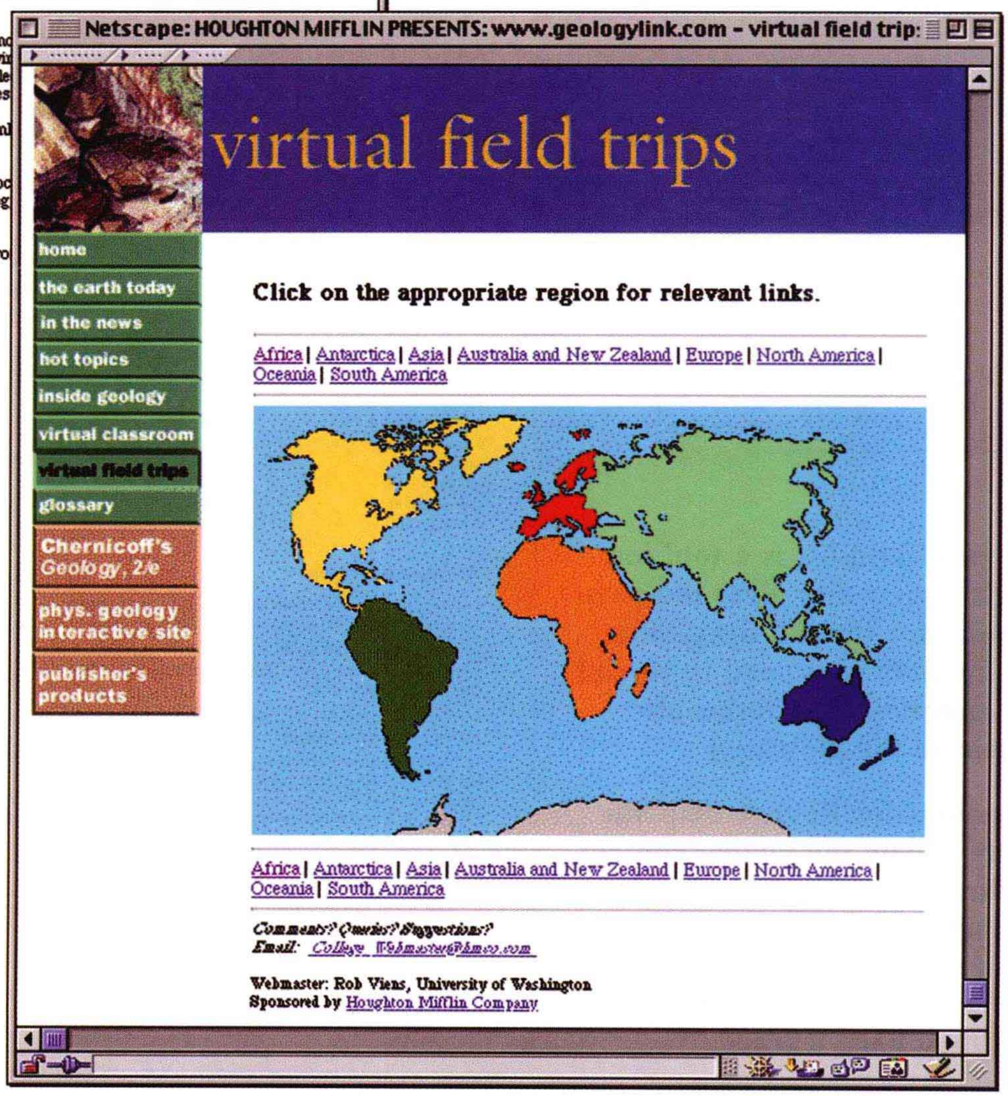
- Hot Topics—Research and discuss the hottest topics in earth science.
- Inside Geology—Link to hundreds of class lectures, web sites, references, news items, organizations, and glossaries on every aspect of geology.





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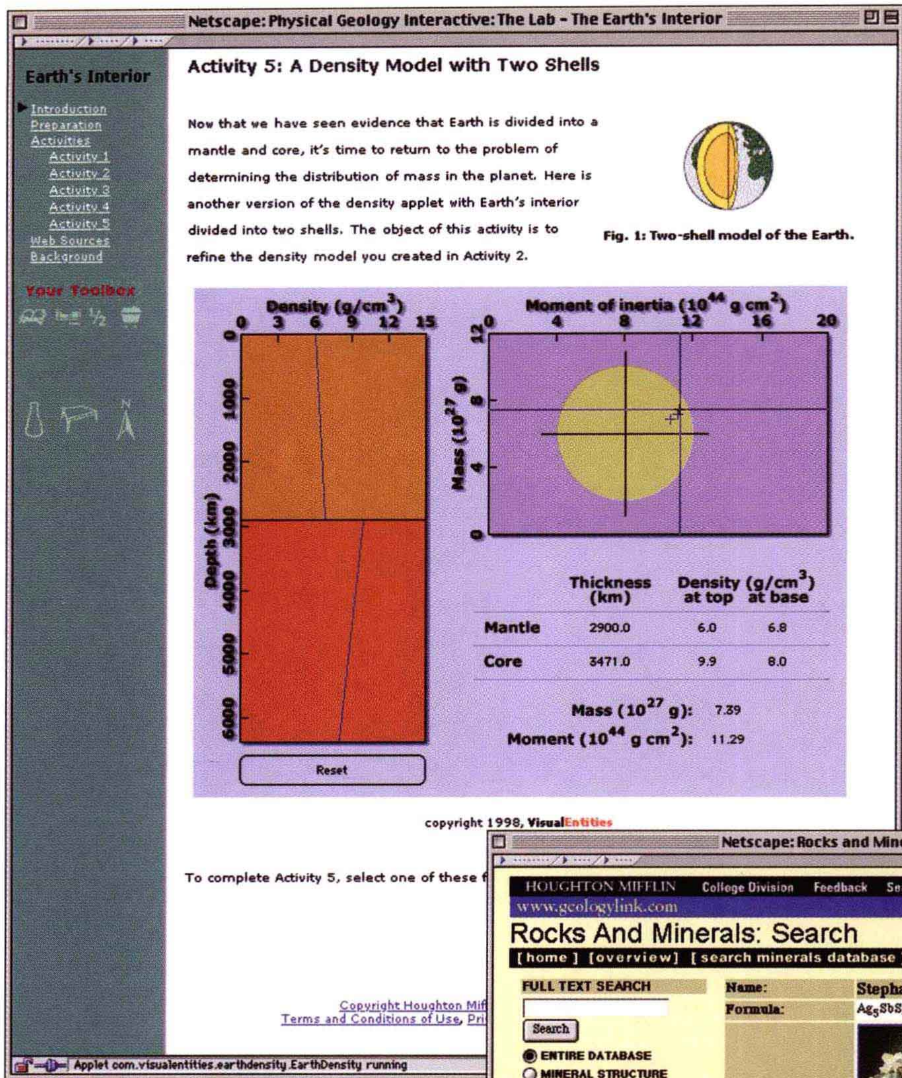
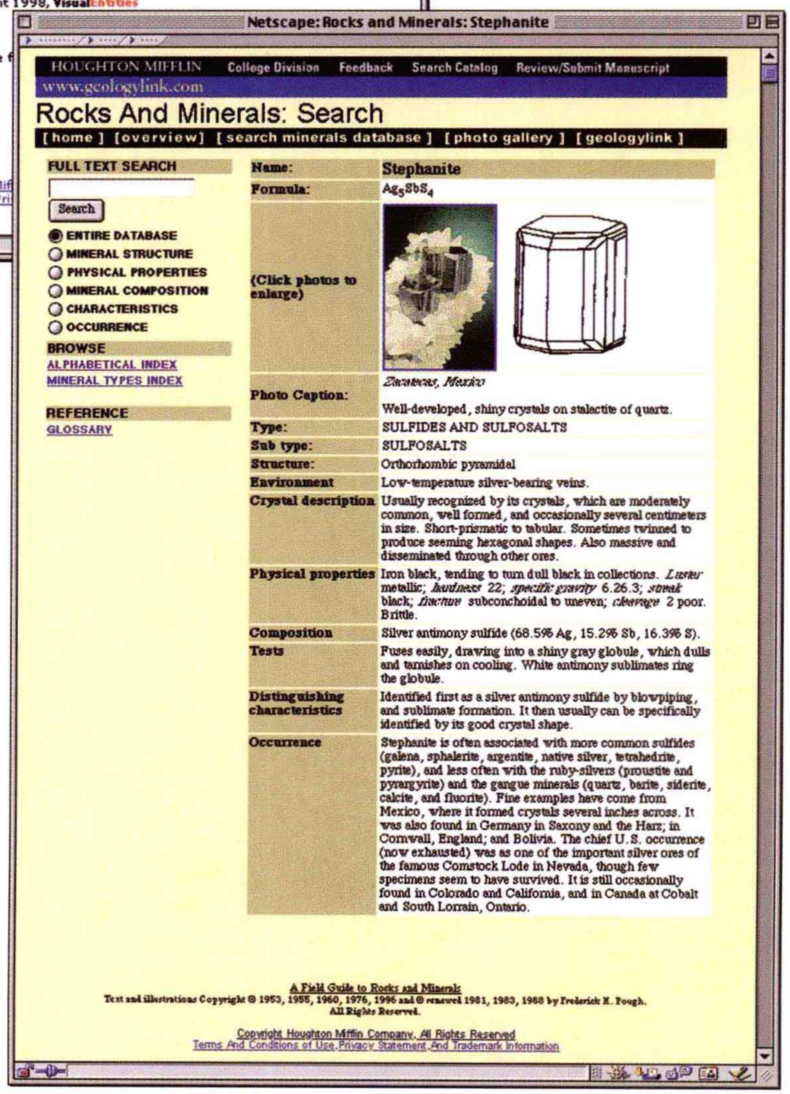
Physical Geology Interactive, an on-line lab manual containing interactive lab exercises, animations, active periodic table, rock gallery, and exercises that can be handed in to the instructor.





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Contents in Brief